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CONTROL OF BRIDGE SCOUR BY SPUR DIKES

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A Report for

C.E. 422 - Hydraulic Research
(3 Credit Hours)

by

Robert P. Apmann
Syed M. Ali

Submitted to

Professor J. B. Herbich

Bethlehem, Pennsylvania

May, 1962

FRITZ ENGINEERING LABORATORY
LEHIGH UNIVERSITY
BETHLEHEM, PENNSYLVANIA

FRITZ LABORATORY REPORT No. 280.17

A C K N O W L E D G E M E N T

The present laboratory study is a part of the project on spur dikes being conducted by the Hydraulics Division of Fritz Engineering Laboratory, Lehigh University, and sponsored in part by Messrs. Modjeski and Masters, Consulting Engineers, of Harrisburg, Pennsylvania.

The authors feel deeply indebted to Professor J. B. Herbich, Chairman of the Hydraulics Division, for his kind guidance and valuable suggestions throughout the study. They are also grateful to Mrs. Nedalyn Stuart for her meticulous typing, Mr. Elias Dittbrenner, and the Technical Staff of Fritz Engineering Laboratory for their technical assistance.

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CONTROL OF BRIDGE SCOUR BY SPUR DIKES

1. INTRODUCTION

The hydraulic design of bridge openings is sometimes limited to finding the waterway area for a mean non-scouring velocity; for the sake of economy some bridges are built to span only part of the width of a stream and so constrict a major portion of the channel. Unless he is very careful, the designer underestimates the severe local scour effects which occur around the abutments at flood discharges. (Fig. 1).

Local non-uniformity of flow, high velocities, and zones of eddying are some of the flow conditions which contribute to deep scour, subsequent undermining of foundations, and failure of the structure.

There are several methods of reducing scour. Foundations can be deepened, the scour hole can be protected from erosion with stones or mats, or spur dikes can be built to lessen the scour and move the scour hole away from the abutments.

Reduction of local scour by spur dikes occurs because the capacity of water to transport material decreases as the dikes smooth some of the flow disturbances. The dikes form a transition which greatly streamlines the flow, reducing the effects of eddies

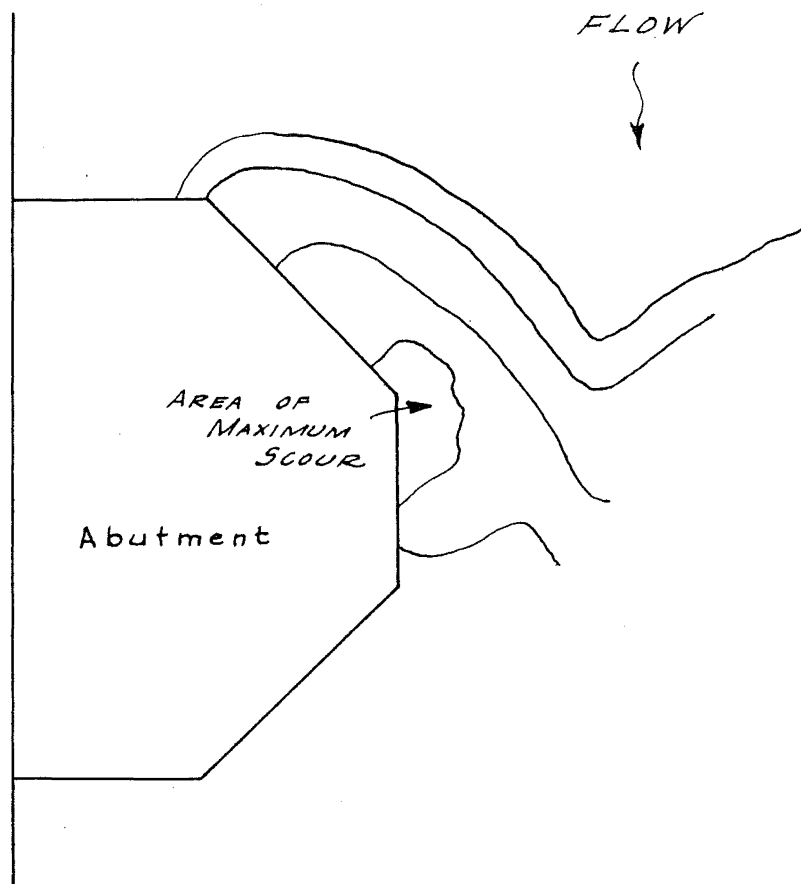


FIG 1. - TYPICAL SCOUR PATTERN
AT ABUTMENT

and separation, and creates more uniform flow conditions. Spur dikes also decrease the backwater depths upstream from the constriction.

2. REVIEW OF LITERATURE

The book, "GREAT BRIDGES OF THE WORLD"^{1)*}, shows that the cutwater, a form of spur dike, has been used for centuries by bridge designers. The Old London Bridge, completed in 1209, used cutwaters to smoothly guide water, ice, and debris through the narrow waterway openings; Oriental culture of the same period conceived and built the wooden cantilever bridge of the type at Srinagar, India. Most of these bridges were built on a soft foundation which scoured easily, and the solution to erosion was the cutwater built around each pier. Another safety factor was included, the building of piers of stacked logs forming an open network. During peak flow periods the river flowed through the open piers.

Research on bridge scour has been done both to study the scour phenomena and to find means to reduce scour.

Some early laboratory studies to understand scour were carried out in 1873 in France and 1894 in Germany. In this country, the Iowa Institute of Hydraulic Research started working on the

*Superscript numerals refer the reader to the bibliography at the end of the report.

problem in 1947 and, after extensive research²⁾, found ways of predicting scour depth at the bridge pier so that foundations could be designed accordingly. Unfortunately, very little work was done on abutments.

It was found that depth of scour was independent of the velocity of flow and the sediment size. However, it increased with increased depth of flow and was proportional to the degree of disturbance. Rounding of abutment corners reduced the scour depth. It was also suggested that an attempt should be made to decrease the velocity in the vicinity of the abutment.

³⁾
Professor Posey studied the scour around a pier in the Rocky Mountain Hydraulics Laboratory and introduced a unique way of studying the effects of turbidity by observing its action through a transparent pier made of glass. An advantage in the method was that the depths of scour could be instantly and accurately determined, eliminating the changes which occurred after draining the water from bed. In the same laboratory, experiments were made with flexible mat around the pier and was shown that scour can be reduced to a considerable degree thereby.

Along with these studies of pure understanding and evaluation of scour phenomena, some work was done to reduce this scour by

using spur dikes. Initiating research in this country was the Georgia Institute of Technology,⁴⁾ where work was done on timber dikes, showing the ability of spur dikes to improve the effectiveness of the bridge opening. For spill-through type abutments, a dike 0.08 as long as the width of opening placed at a distance of 0.08 W from the beginning of the abutment curve and at an angle of 0° to the flow proved to be the best. No mention of discharge or percentage opening was made.

Colorado State University and Lehigh University started working on spur dikes almost simultaneously. In contrast to Colorado State University studies with moveable bed models, Lehigh University worked with a fixed bed model.

Using an elliptical dike, it was found out at Colorado⁵⁾ that a dike with ratio of $2\frac{1}{2} : 1$ gave the best results. It was also found that depth of scour at the abutment was inversely proportional to the length of dike. It was also noticed that scour depth was a direct function of embankment length, or percentage contraction. Design criteria were given for spill-through type abutments. Knowing discharge and length of embankment, a chart gives depth of scour against length of dikes. A very limited study was made of 45° skewed openings. The depth of scour decreased with increase of length of dike in case of downstream skew, but for upstream skew,

length of dike seemed to have no effect on the depth of scour.

Carle and Kable⁶⁾ at Lehigh first studied the effects of dikes on flow through bridge openings, and then Kable⁷⁾ went ahead and produced a curve giving length of dike against abutment opening.

Using a fixed bed⁸⁾, Hartzel and Kareymyr used spur dikes to obtain uniform distribution of velocity. It was seen that dike 10 cm away from the abutment and 10° angle gave best results. However, these tests were not conclusive.

3. PREVIOUS RESEARCH AT LEHIGH UNIVERSITY

A review of previous spur dike research at Lehigh is necessary to understand the current research program. Three research reports preceded the start of the recent work:

Carle, R. J.	THE EFFECT OF SPUR DIKES ON FLOOD FLOWS THROUGH HIGHWAY BRIDGE ABUTMENTS
Kable, J. C.	THE DETERMINATION OF THE LENGTH OF SPUR DIKES FOR FLOOD FLOWS THROUGH HIGHWAY BRIDGE ABUTMENTS
Herbich, J. B. Apmann, R. P. Ali, S. M.	STATUS REPORT OF RESEARCH PROJECT ON THE EFFECT OF SPUR DIKES ON FLOOD FLOWS THROUGH HIGHWAY BRIDGE ABUTMENTS ⁹⁾

Carle and Kable⁶⁾ reported the results of tests of fixed bed models of bridge abutments placed normal to the flow. For a variety of flow conditions and abutment openings they obtained

velocity and depth data. They demonstrated the ability of spur dikes to produce smoother flow conditions, and it was observed the small stub dikes compensated for the eddying produced at the downstream corners of the abutment by the addition of spur dikes.

It was argued by Kable⁷⁾ that,

"if a spur dike can be extended upstream from the abutments until it intercepts a velocity which would not cause scour around the dike itself, then a transition could be formed which would channel the flow smoothly through the abutment opening."

The velocity at which separation occurred at the end of dike was taken to be the velocity which would just cause scour. Various tests yielded a value of one foot per second. Accordingly, calculations were made for various openings to find the distance from the abutment upstream to a point where the velocity was just less than one foot per second. From these distances came a curve giving length of dike versus width of abutment; the curve showed a need for longer dikes with increasing width of opening.

Kable erred first in failing to realize that introducing spur dikes into the flow changes its velocity and streamline pattern, thereby negating the entire basis for his determining the length and shape of dike. He erred secondly in equating scour velocity with separation velocity.

4. RESEARCH PROGRAM

The ultimate objective of the present research was to provide engineers with information to properly design spur dikes. Leading to this objective was the more immediate goal of giving direction to further research by determining the effects of flood flow on selected abutment and dike shapes.

Because no analytical methods were present for solving the problem, it had to be attacked from an experimental view point. The choice of testing was between moveable and fixed bed models, the latter method being initially chosen for several reasons; by eliminating some geometric variables the fixed bed model simplified the problem; by reducing the time and effort taken for each test, the method allowed more tests to be made; the direction of moveable bed testing could be determined by conditions developed in fixed bed models.

A general problem exists in correlating the results of tests on fixed bed and moveable bed models. From answers obtained in fixed bed tests, how can one foresee conditions in the moveable bed test? In most cases only qualitative relations exist and for each example these relations need to be checked by performing several tests under similar conditions.

The scour in a moveable bed model depends on various things; flow disturbances, such as turbulent fluctuations and eddies; and local non-uniformity of flow, velocity gradients and changes in slope of the energy line. In a fixed bed model the effects of these factors can be seen by observing local disturbances and measuring non-uniformity of velocities. For example, one should expect deeper scour at abutment corners and at the head of dikes where large velocity gradients and depression of water surface are encountered.

For the fixed bed tests, we assumed the best effect of spur dikes to be attained when a uniform velocity distribution was achieved across some important section of the opening. Consideration was also given to velocity readings made at critical points such as along and at the head of dikes. How well this assumption was verified by actual testing in moveable bed models is discussed in a later section of the report.

The research program was divided into two phases, one in which 60° skewed abutments were tested, and another in which abutments placed normal to the flow were tested. In the latter phase several moveable bed models were built to supplement

the fixed bed studies and check the assumption of identifying uniformity of flow with erosive potential.

For each test phase there were four significant parameters; discharge, abutment opening, length of spur dike, and a dike angle. For simplicity, one discharge, 3 cfs, was chosen for all tests - a discharge sufficiently large to yield severe flood conditions in the prototype. Also, most tests were run with straight dikes.

Primarily, tests were run for the following situations:

Skew Angle 60°

Lengths of dike:	18"	27"	36"
Dike Angles:	0°	15°	30°
Abutment Opening:	27-1/2"	41-1/2"	59-1/2"

Skew Angle 90°

Lengths of dike:	18"	27"	36"
Dike Angles:	0°	10°	20°
Abutment Opening:	27-5/8"	52-1/2"	41-7/8"

In addition, tests were run without dikes for each opening.

5. RESEARCH PROCEDURE AND APPARATUS

Along with visual and photographic observations, velocity and depth data were recorded. Readings were taken along the centerline of abutments and at several points along the dikes. Some velocity and depth readings were also taken upstream in the

channel centerline. Because the flow variation was more concentrated near the abutments, velocities were read at closer spacings there. The 3 cfs discharge usually produced a depth of about 0.4 feet at the center of abutments for a tailgate height of 2-1/2".

In the previous reports, the effectiveness of using stub dikes had been shown, so that in all the tests with spur dikes a stub dike 12" long was used. Placement of the dikes is shown in the definition sketches, Figures 2 and 3.

The spur and stub dikes, made of sheet metal, were ended with 6" diameter circular concrete cylinders. A new "Ott" Midget Laboratory current meter was put into service for which the calibration chart is Figure 4.

Figure 5 shows the multipurpose tank used for the experiments. But, for the addition of an improved crushed stone baffle, other fixtures are the same equipment used and reported in previous spur dike work. 6) 7) 9)

Examples of the data taken are shown in Figure 6. The remainder of the data is on file in the Fritz Engineering Laboratory, Lehigh University.

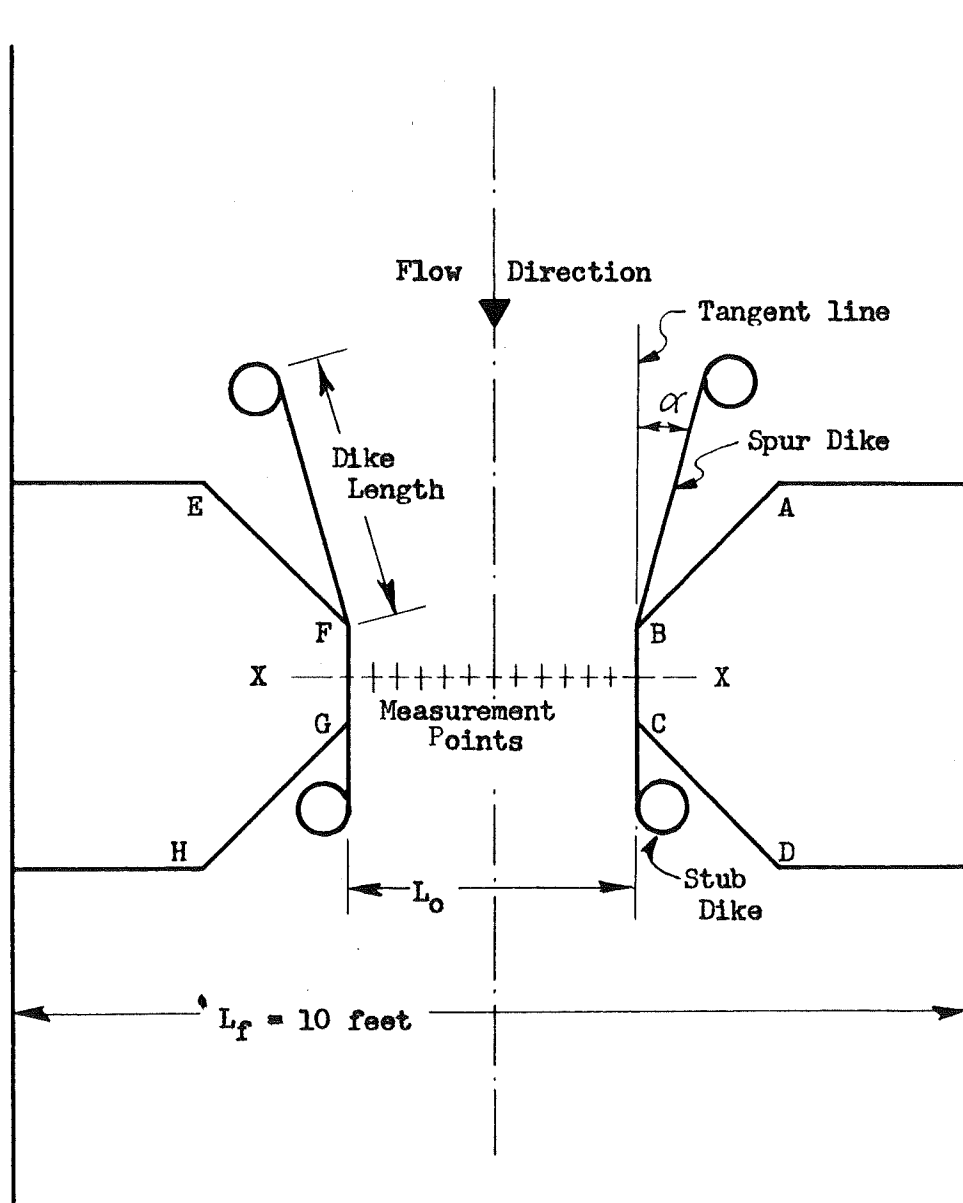


Fig. 2 - Definition sketch for 90° approach flow.

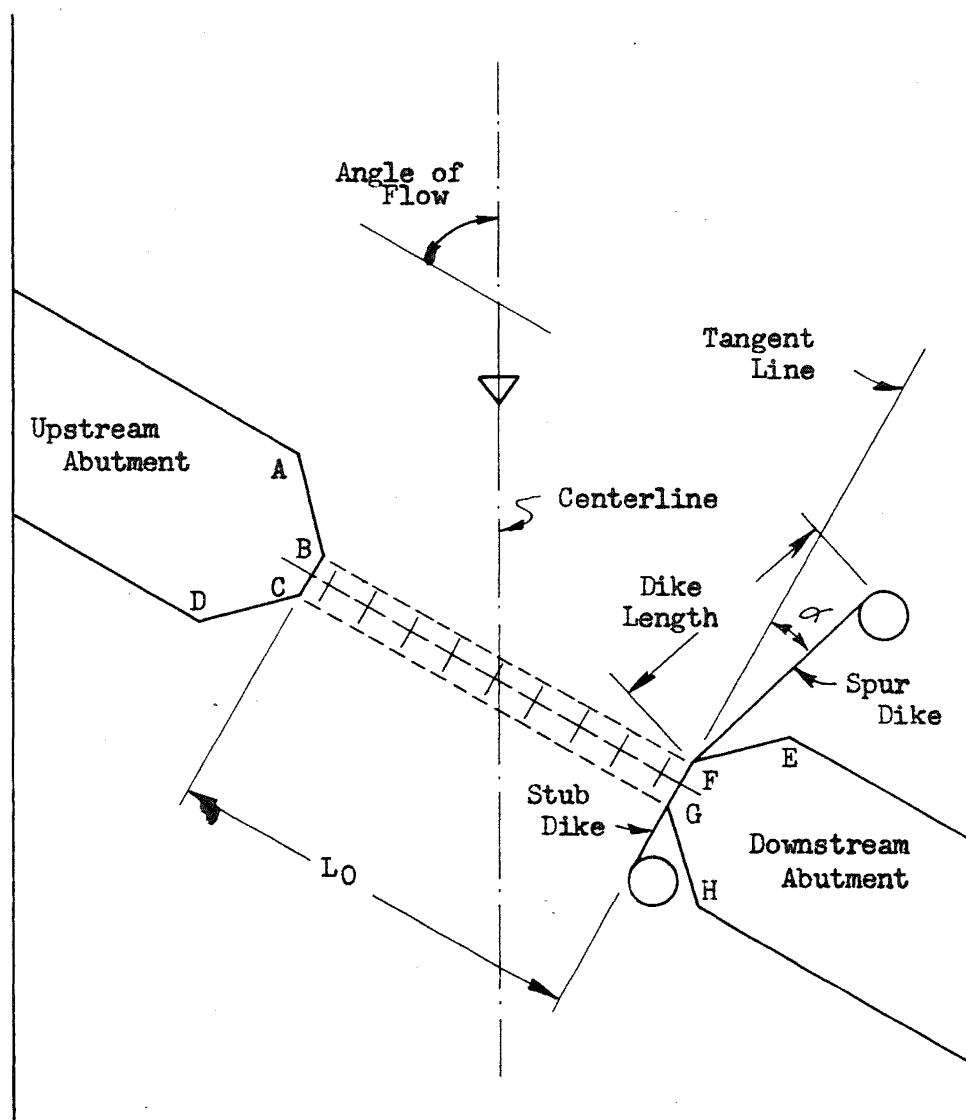


Fig. 3 - Definition sketch for skewed abutment

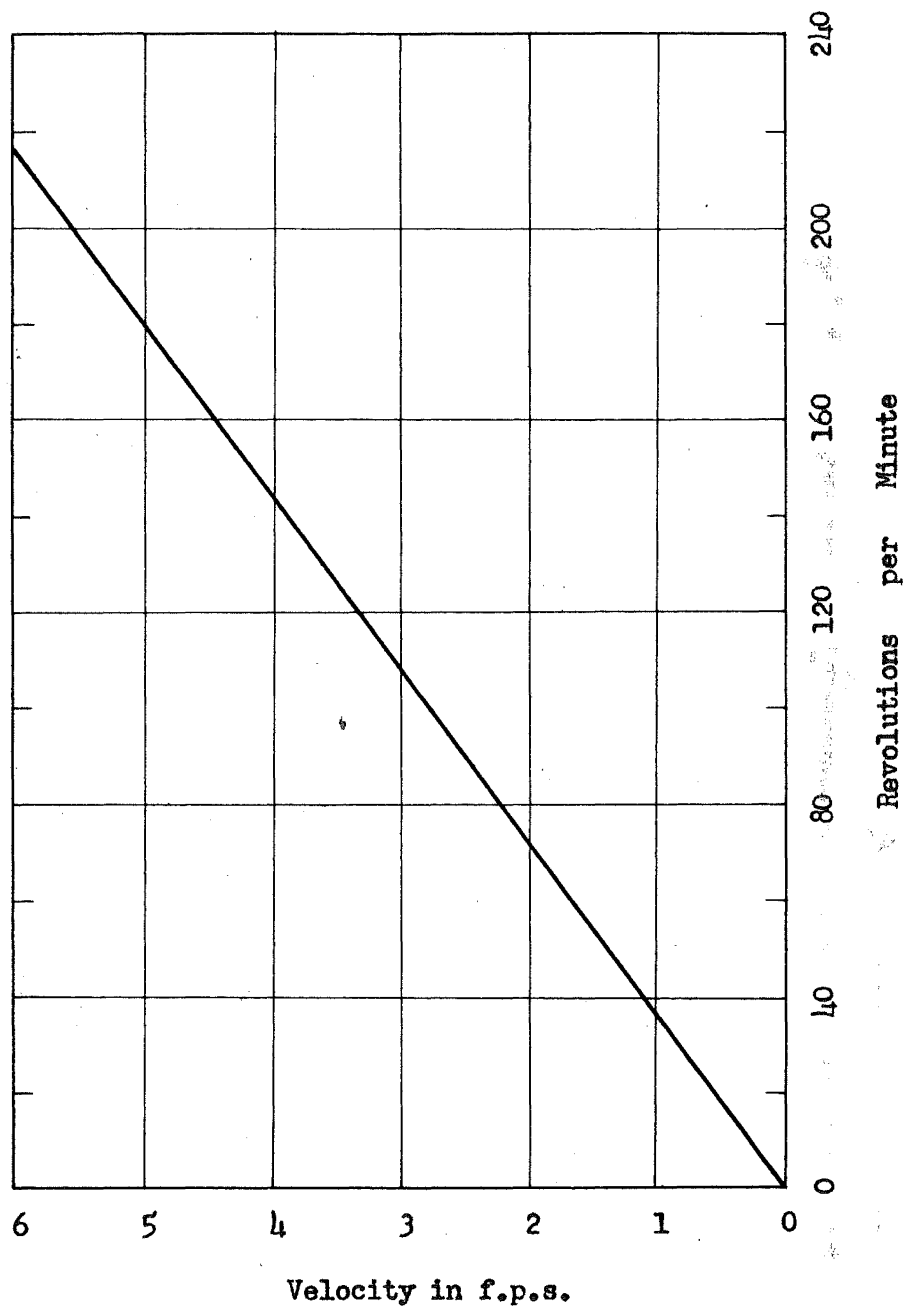
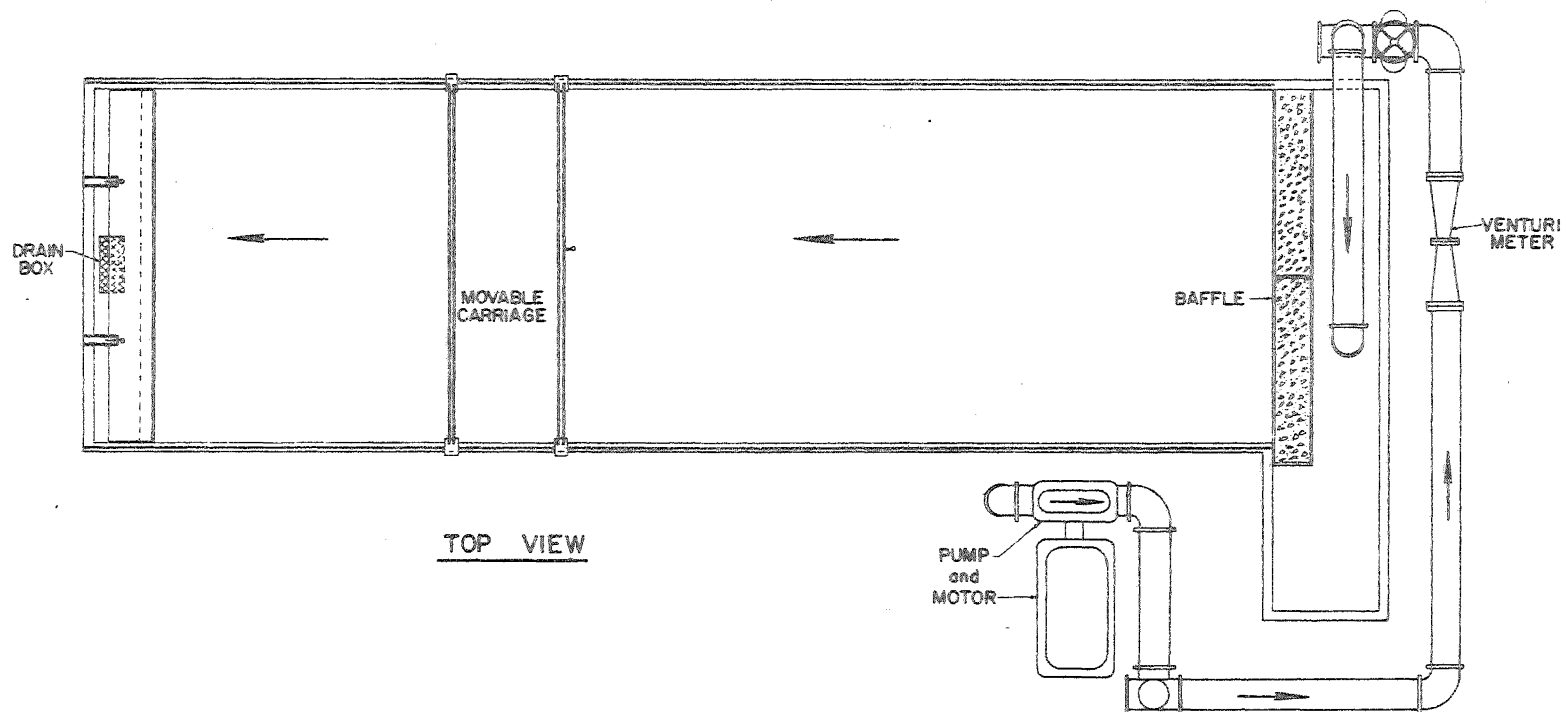
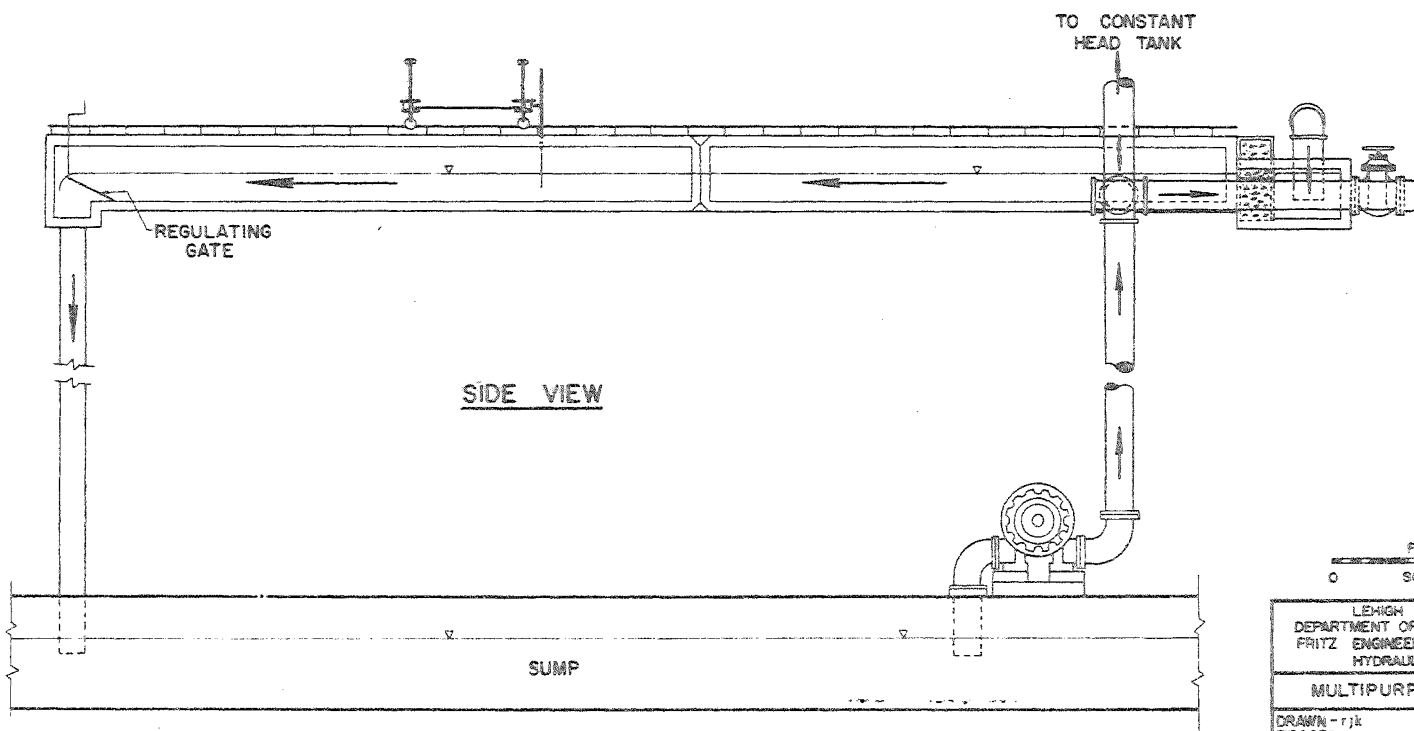


Fig. 4 - OTT Current Meter Calibration Chart



TOP VIEW



SIDE VIEW

FEET
0 SCALE 5

LEHIGH UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING
FRITZ ENGINEERING LABORATORY
HYDRAULICS DIVISION

MULTIPURPOSE TANK

DRAWN-rjk DATE-APRIL 1961
TRACED-rjk CHECKED-jbh
DRAWING NO. 20

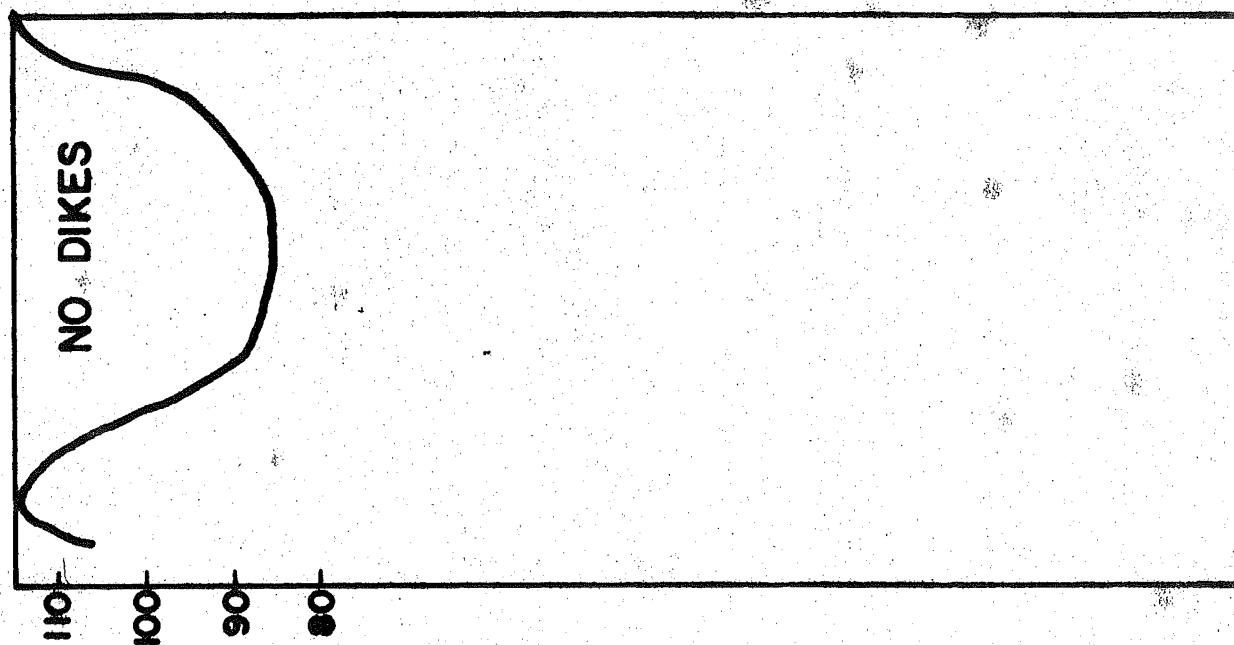
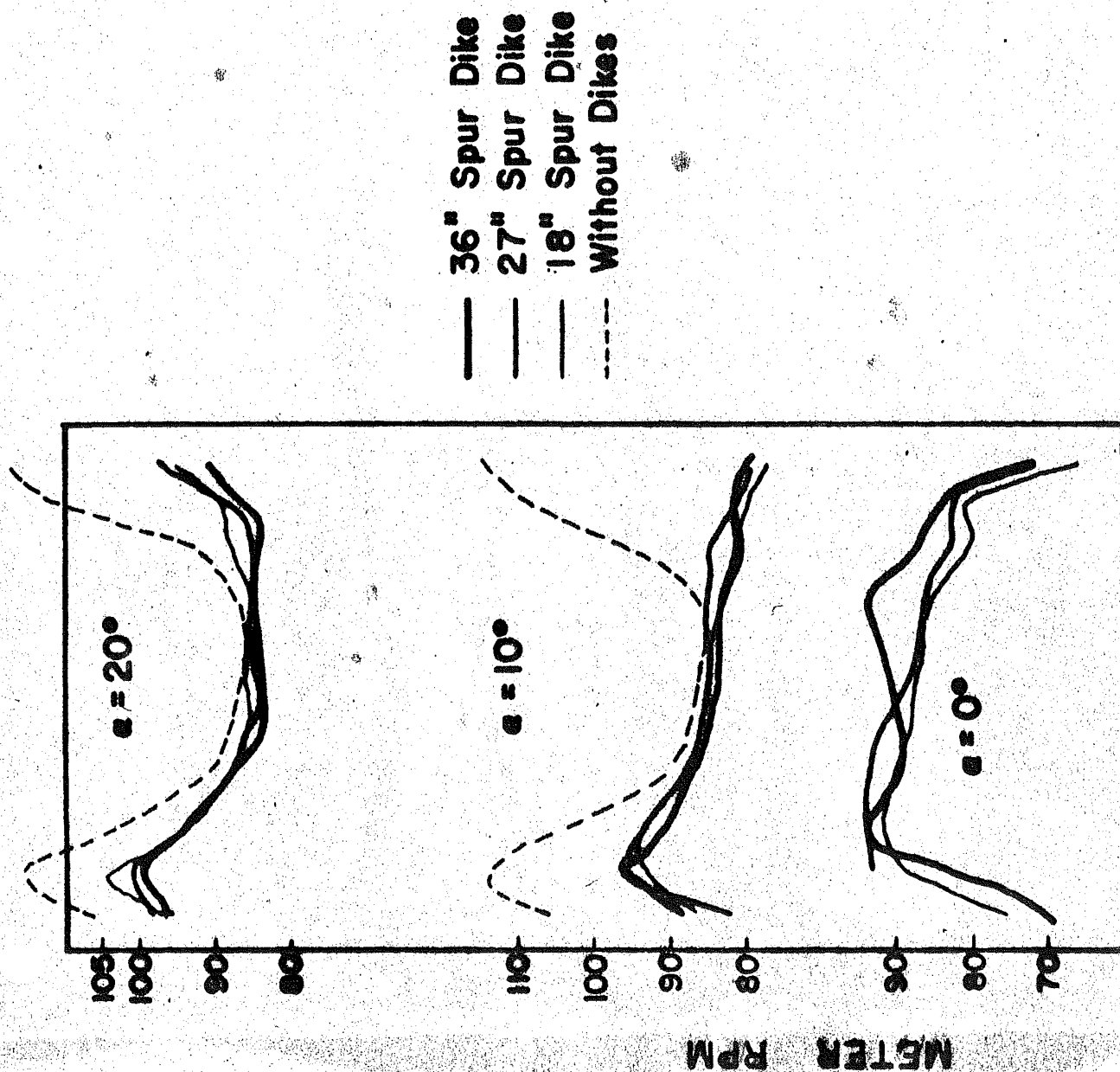


FIG. 6 VELOCITY DISTRIBUTION BETWEEN ABUTMENTS
 90° APPROACH, DIKE ON DOWNSTREAM ABUTMENT, PERCENTAGE OPENING 34.9
 DISCHARGE 2.92 cfs

6. ANALYSIS OF DATA

6.1 Dimensional Analysis

In designing the research projects and analyzing data, it was natural to turn primarily to the methods of dimensional analysis, for the complexity of the problem prohibited the use of the purely mathematical methods. Dimensional analysis yielded parameters which enabled quantitative reduction of empirical data.

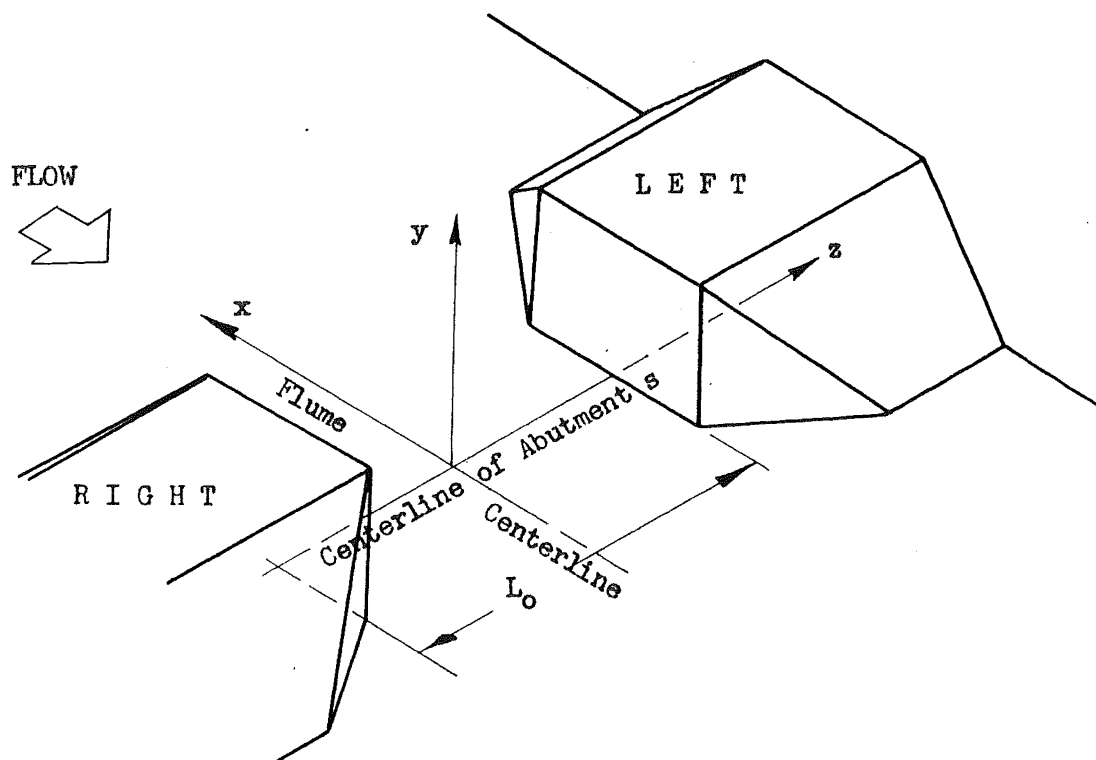
The variables involved were:

Geometry

f_D	=	Shape of Dike
f_A	=	Shape of Abutment
ϕ	=	Angle of Abutment Skew
α	=	Angle of Dike
L_F	=	Waterway Width
L_O	=	Width of Abutment Opening
L_D	=	Length of Dike
x, y, z	=	Coordinate Axes (See Fig. 7)

Dynamics

v	=	Velocity
fv	=	Velocity Distribution



Dimensionless Coordinates: x/L_0 , z/L_0

Fig. 7 - Definition sketch for coordinate axes.

Dynamics (con't)

g	=	Gravitational Acceleration
Q	=	Discharge
ρ	=	Fluid Density
μ	=	Viscosity

Sediment Transport

τ_o	=	Boundary Shear Stress
ρ_s	=	Density of Channel Material
d_s	=	Mean Particle Size
y_s	=	Depth of Scour
w	=	Fall Velocity

The problem of choosing significant parameters was complicated and simplifications had to be introduced to yield tractable results. By testing in fixed bed models the sediment factors were eliminated. Straight dikes were used and a standard Pennsylvania Department of Highways' abutment was used. Froude number similarity was eliminated because constant discharge was chosen. All tests were run at sub-critical flow.

The most important ratios which evolved were:

$$\frac{L_o}{L_F} = \frac{\text{Width of Abutment Opening}}{\text{Width of Flume}}$$

$$\begin{aligned}\frac{L_D}{L_O} &= \frac{\text{Length of Dike}}{\text{Width of Abutment Opening}} \\ \frac{Z}{L_O} &= \frac{\text{Width}}{\text{Width of Abutment Opening}} \\ \frac{X}{L_O} &= \frac{\text{Length}}{\text{Width of Abutment Opening}} \\ \frac{V}{V_O} &= \frac{\text{Velocity at a Point}}{\text{Uniform Approach Velocity}} \\ \frac{V_w}{V_{w/o}} &= \frac{\text{Velocity at a Point with Dikes}}{\text{Velocity at a Point without Dikes}}\end{aligned}$$

6.2 Use of Continuity Equation

For a rectangular channel the continuity equation may be written

$$Q = Vby,$$

where Q = discharge, V = mean velocity over the section, b = width, and y = depth.

When the equation is written in terms of natural logarithms,

it is $\ln Q = \ln V + \ln b + \ln y,$

and when differentiated, we have

$$\frac{dQ}{Q} = \frac{dV}{V} + \frac{db}{b} = \frac{dy}{y}$$

If the discharge is constant, as in our tests, then $dQ = 0$.

$$\text{Thus, } \frac{dV}{V} + \frac{dy}{y} = \frac{db}{b}$$

In a uniform flow situation, the velocity and depths are constant over the whole cross-section. Although in the testing this did not actually occur, sufficient data was taken to enable the determination of mean velocity and depth over the centerline cross-section. Thus, after some computation, it was possible to treat the channel as one of uniform flow.

In a channel the width of flow calculated on the basis of uniform velocity and depth may not be the same as the actual width of the channel. Because of turbulence, eddying, separation, and convergence of streamlines, the efficiency of transmission or conveyance of the channel will be decreased.

When spur dikes are added to the channel contraction the effectiveness of conveyance increases, because the spur dikes channel the water into smoother flow patterns (Fig. 8). If the effective width of the channel without spur dikes is called b_0 and the effective width of the channel with spur dikes is called b , then the difference between the two is

$b - b_0 = nb_0 - b_0$, where n is a measure of the effectiveness of transmission of the channel. The difference will be positive,

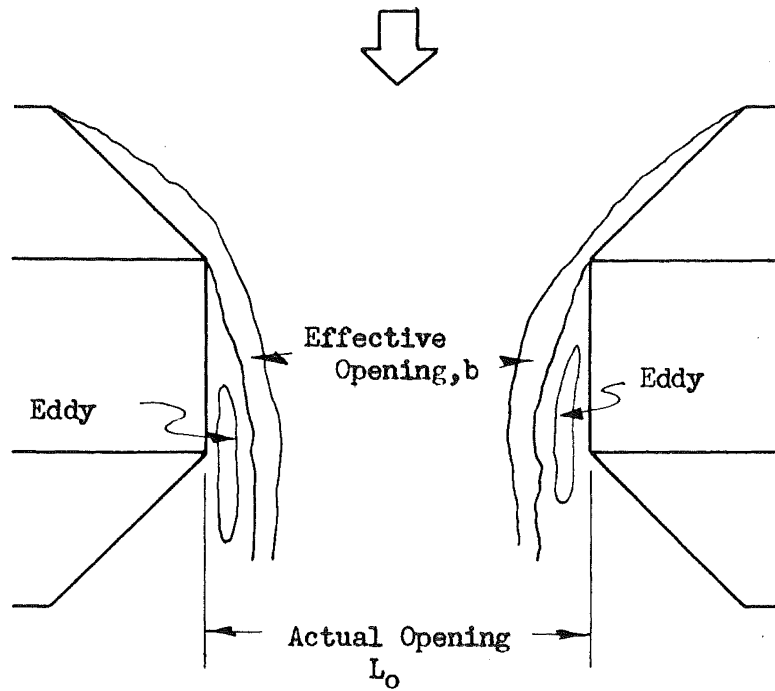


Fig. 9 - Decrease in effectiveness of actual abutment opening, L_o , due to separation and eddies.

since b is assumed greater than b_o .

Returning to the differential continuity equation for steady flow, we may write this in terms of differences instead of derivatives as

$$\frac{\Delta V}{V_o} + \frac{\Delta y}{y_o} = \frac{(n - 1) b_o}{b_o}$$

and since the b_o terms cancel

$$n = 1 - \frac{\Delta V}{V} - \frac{\Delta y}{y}$$

In the analysis the differences in average velocity and depth were computed. Since, in all cases, the installation of spur dikes caused a decrease in average velocity and a decrease in depth, n was found to be greater than one, which shows an increase in the efficiency in transmission of the channel.

7. TESTING OF 60° SKEWED ABUTMENTS

7.1 Observations

It had been observed while testing 60° skewed openings (Fig. 3) that the upstream abutment acts similar to a dike, and that without dikes the conditions of flow adjacent to the upstream abutment were not as severe as near the downstream abutment, thus it was decided to test with the dike only on the downstream abutment.

Three openings ($27\frac{1}{2}$ ", $41\frac{1}{2}$ ", and $59\frac{1}{2}$ ") were tested with three lengths of straight dikes ($L_d = 18$ ", 27 ", and 36 "). Angle α was varied from 0° to 30° , but after one test it was found that $\alpha = 30^\circ$, produced local high velocities and eddying, at Point F. After that only two angles, $\alpha = 0^\circ$ and $\alpha = 15^\circ$, were tested.

Because the flow is more complex than the case of 90° approach, velocity measurements along one line x-x (centerline of abutment) would have been insufficient, thus velocities were also taken along the line B-F and C-G.

Observations showed that using a dike only on the downstream abutment, while improving the conditions of flow on the downstream side, worsened the conditions on upstream side as compared to flow condition without any dike. It was seen that the narrowed is the opening the more pronounced is this effect. For a wide opening, a spur dike on the downstream side did not change the flow near the upstream abutment.

Noting the improvement caused by a dike on the flow in the vicinity of the downstream abutment, it was decided to make tests with dikes on both sides. Two openings ($59\frac{1}{2}$ ", $41\frac{1}{2}$ ") were used. It was found that dikes on both sides produce much more

favorable flow as compared to dike on one side.

7.2 Conclusions

In testing one straight spur dike attached to the downstream abutment, analysis of data led to the following conclusions:

- 1) There is no significant difference in the action of the different lengths of dike. Some minimum length of dike exists, but this length cannot be found from the data.
- 2) The effect of different dike angles is small, but as the opening increases the angle should be slightly increased. While zero angle is better for the narrow openings, 15° is best for the widest.
- 3) As the opening decreases the dike effect becomes more pronounced on the upstream (right) side in increase of velocities, while the velocity reduction on the left is about the same for all openings.
- 4) Spur dikes used only on one side could be detrimental by causing locally higher velocities in the severely constricted cases.

After testing two dikes attached to the abutments and shaped as in Fig. 9, two more conclusions were drawn:

- 5) The shape and placement of dikes is highly important.

6) The use of dikes on both abutments significantly lowers the velocities on the upstream abutment. Their action on the downstream abutment is not too different from the use of a single dike. In addition, a very uniform velocity distribution is obtained with the curved dikes.

7.3 Design Recommendation

In placing spur dikes on 60° skew abutments, it is recommended that two dikes be constructed (Fig. 9). The downstream dike should be only very slightly curved and the upstream dike given more sharp curvature. Both must be built tangent to the abutment face. A spiral curvature will be satisfactory.

8. TESTING OF 90° APPROACH FLOW

8.1 Performance Criteria and Indicators

The performance of spur dikes should be measured on the ability to limit scour about abutments and dikes to a safe value, for when a dike is built it becomes a part of the whole bridge structure and thus should be so designed that it not only shields abutments from excessive scour but is itself stable.

Unlike moveable bed models, the fixed bed model is unable to demonstrate the performance by amounts of scour and deposition

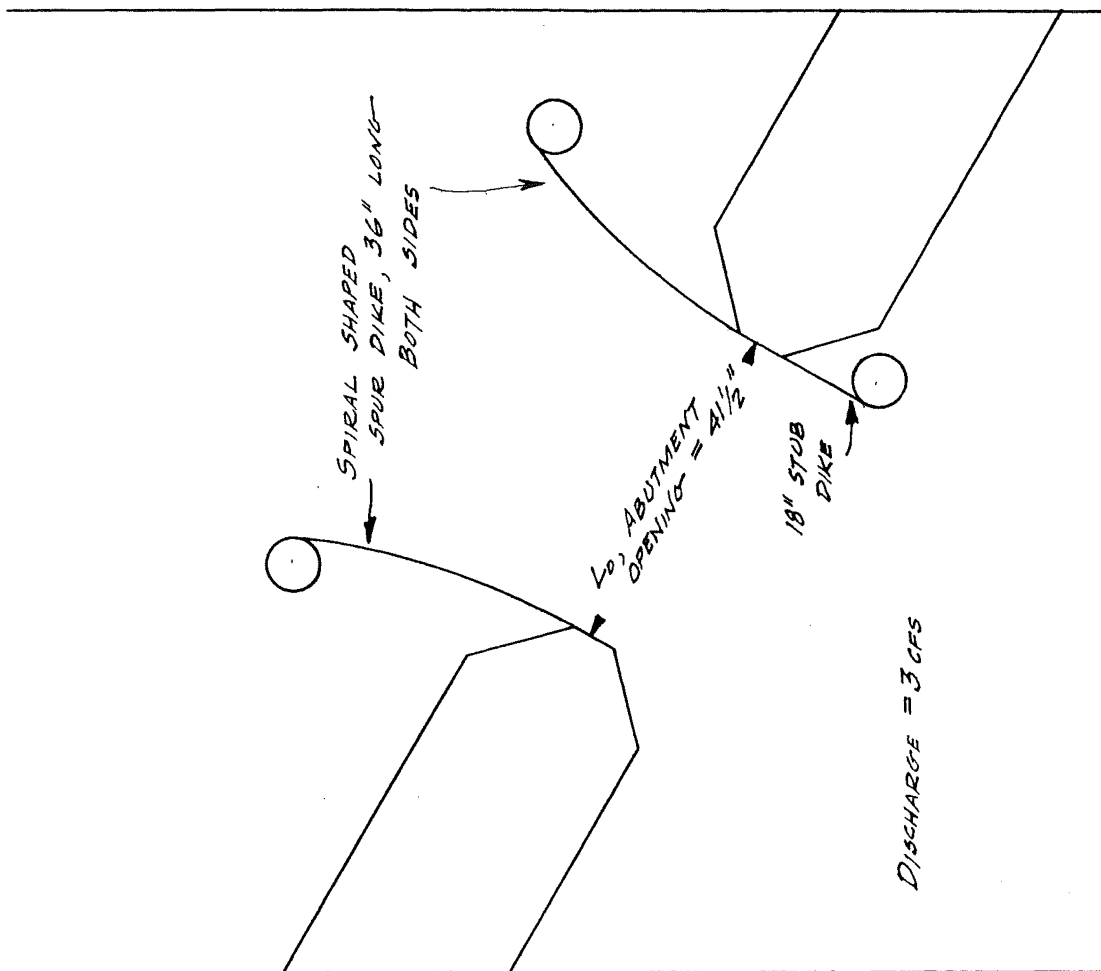


FIG 9 - CURVED SPUR DIKES USED IN
60° APPROACH FLOW

at significant points in the model; some different indicators must be chosen to analyze the effectiveness of dikes. Four indicators measured the performance of dikes in the fixed bed models:

1. Transmission effectiveness, n .
2. Reduction of mean velocities along the centerline of abutments.
3. Velocity distribution along the abutment centerline.
4. Velocity at the head of the dike.

The first indicator, transmission effectiveness, n , was derived in a previous section of the report from considerations of continuity of mass flow. It describes the change in effective width of the flow passage after building spur dikes. Values of n greater than 1.0 indicate an increase in effective width of opening. Referring to Figure 8, one sees that the parameter is related to the effect of eddies on the flow.

The second indicator, reduction of mean velocities along the abutment centerline, shows the ability of dikes to generally lower velocities in that section. However, it does not show whether one or another spur dike configuration produces the lowest absolute

mean velocities or whether the postulated desirable uniformity of velocity has been achieved. For this reason, the velocity distribution along the abutment centerline should be considered as an important indicator; an indication of velocity uniformity comes from ratio of maximum to minimum velocities measured in the centerline section. The lowest value of the ratio is indicative of narrowest range of velocities and thus the most uniform distribution.

The first three indicators were measured across the centerline of abutments, that section being in the critical area of abutment scour and thus of great importance. Stability of the dike is also important and the velocity at the head of the dike was measured and considered an important indicator of conditions in that area.

8.2 Observations

Visual and photographic observations showed the occurrence of similar flow patterns in all the tests. While the phenomena were similar, the degree of severity seemed to depend on the angle at which dikes were placed.

Three significant phenomena developed in the model:

1. An abrupt change in water surface elevation occurred at the head of dike (Photo Nos. 1 and 2). It was here that the flow direction was rapidly changed by the model geometry; this resulted in high velocities and curvature of streamlines. The effect diminished when the dike angle α was increased, since that produced a wider mouth for the constriction and the flow transition became less abrupt.

2. The depression of water surface where dike was attached to the abutment (Photo No. 3) had similar causes; the geometric discontinuity at that point caused high velocities. Again, the amount of water surface depression depended on dike angle. When $\alpha = 0$, there was no depression (Photo No. 2) since the dike joined the abutment by a tangent. By increasing dike angle, the depression was increased; when $\alpha = 45$, that is, when no dikes were present, the depression was greatest.

Thus, an inverse relation exists between water surface elevation at these two points. When the dike angle is increased, conditions are bettered at the head of the dike, but worsened at its point of intersection with the abutment.

3. Eddies were generated at two points in the model: the

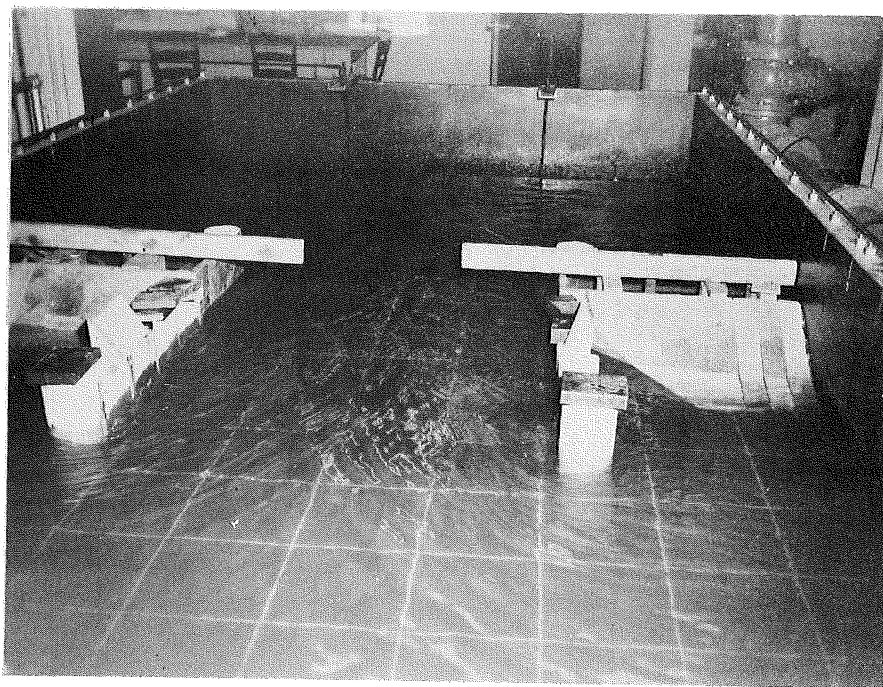


Photo No. 1 - Showing Flow Conditions at Head of Dike

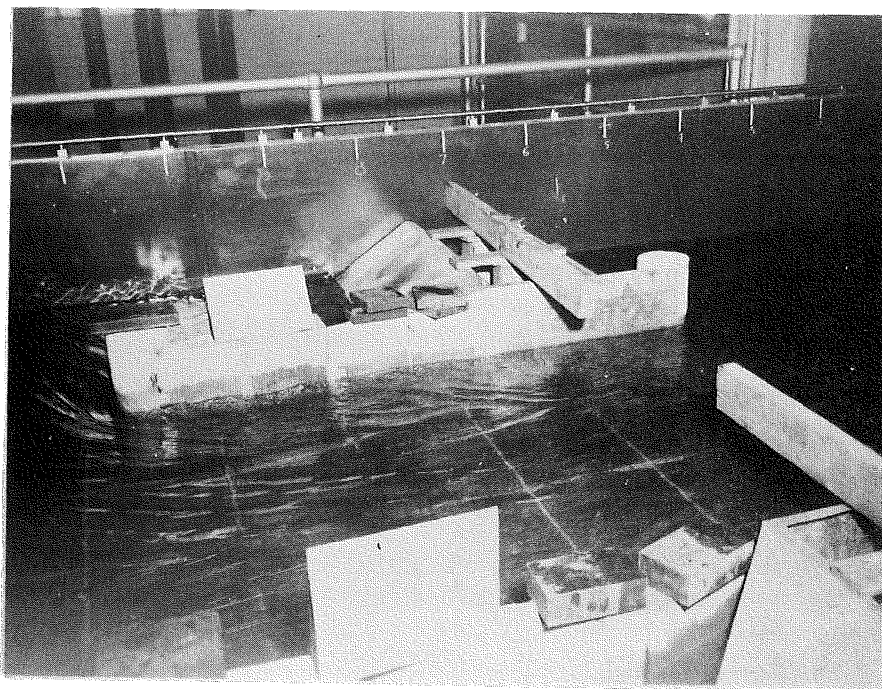


Photo No. 2 - Showing Flow Conditions at Head of Dike
and Top of Abutment



Photo No. 3 - Showing Flow Conditions
for $\alpha = 20^\circ$.

head of dike and at its intersection point with the abutment. As discussed before, the extent and intensity of the eddies interfered with the efficient passage of fluid through the constriction. The dike angle α affected the eddy formation in the same manner as it did to the water surface depression. That is, increasing the angle decreased the amount of eddying from the dike head, but increased the eddying from the intersection point.

8.3 Mathematical Analysis

In Figure 10 the transmission effectiveness, n , is plotted for various abutment opening widths. For smaller percentage openings the three dike angles tend to be equally effective in increasing the efficiency of the opening. However, at the large openings the curves diverge and one sees that a 20° angled dike, in yielding a constant n , is more useful in this respect than zero degree angled dike.

The percent reduction in mean velocity was calculated by

$$\left\{ 1 - \frac{\text{Mean Velocity with Dikes}}{\text{Mean Velocity without Dikes}} \right\} \times 100$$

for the cross-section at the abutment centerline. From Figure 11, we see that for the range in data all dikes reduced mean velocity, but that each dike was most effective in this respect at a certain range of abutment openings.

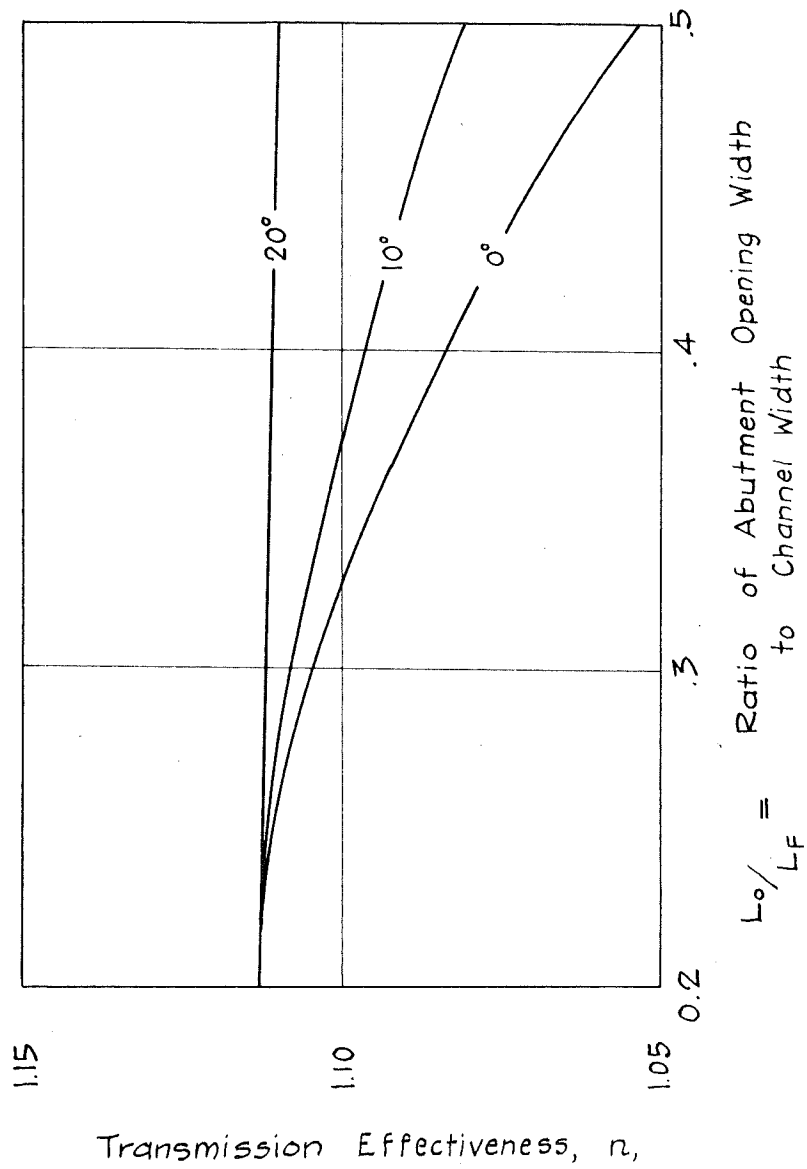


Fig. 10 - Transmission Effectiveness versus Abutment Opening for various dike angles.

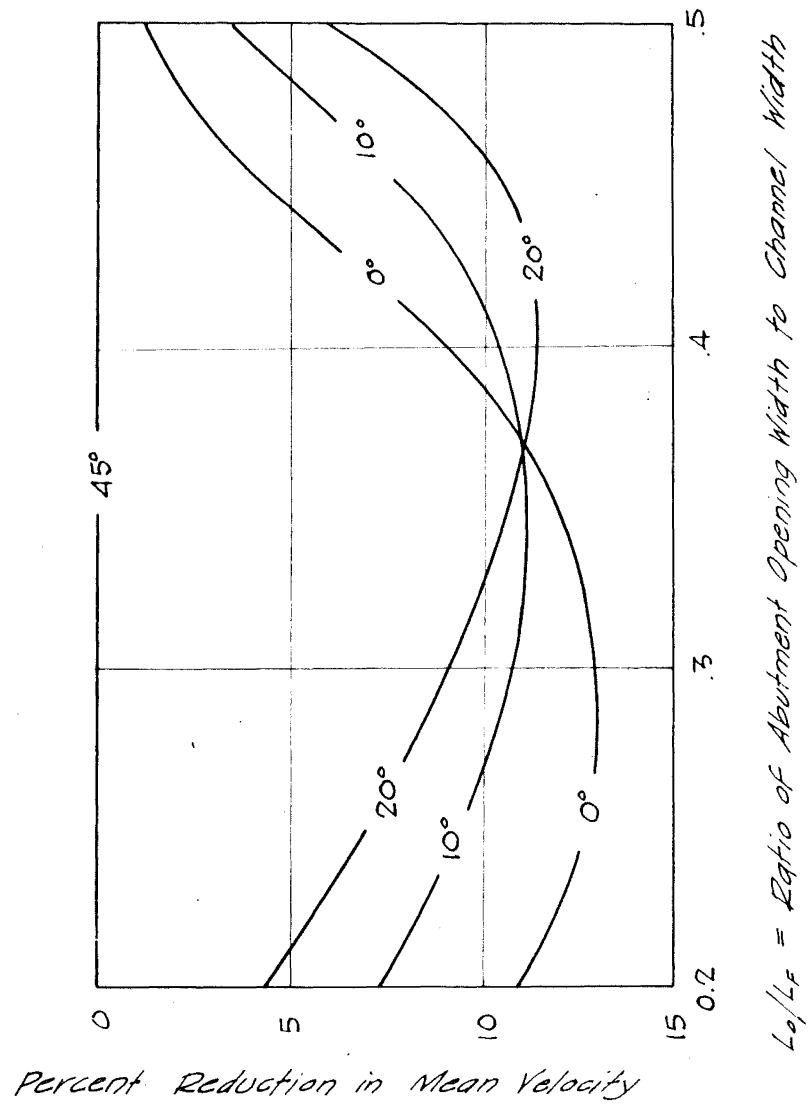


FIG. 11 - Percent Reduction in Mean Velocity across abutment opening for various dike angles

Typical velocity distribution plots are shown in Figure 6. It is seen that, without dikes, the velocity is non-uniform and has its highest values near the abutment. On the other hand, spur dikes decreased boundary velocities and created more uniform velocities.

An analysis of uniformity of velocity distribution is plotted in Figure 12. The difference between maximum and minimum velocities measured across the abutment centerline was divided by the width of opening, thus yielding a measure of the rate of change of velocity across the section. The plot shows the more uniform velocity distribution to occur with dikes, and particularly with dike angles 10° and 20° .

The velocity at the head of dikes was measured and is shown in Figure 13. Except for zero-degree angled dike, the abutment opening seems unimportant, the dike angle being more significant. It seems reasonable to assume that greater scour would occur at the head of a zero-angled dike than in the other cases.

8.4 Curved Dike Tests

The observations of flow patterns discussed in section 8.2 suggested two improvements in dike shape; first, the discontinuity

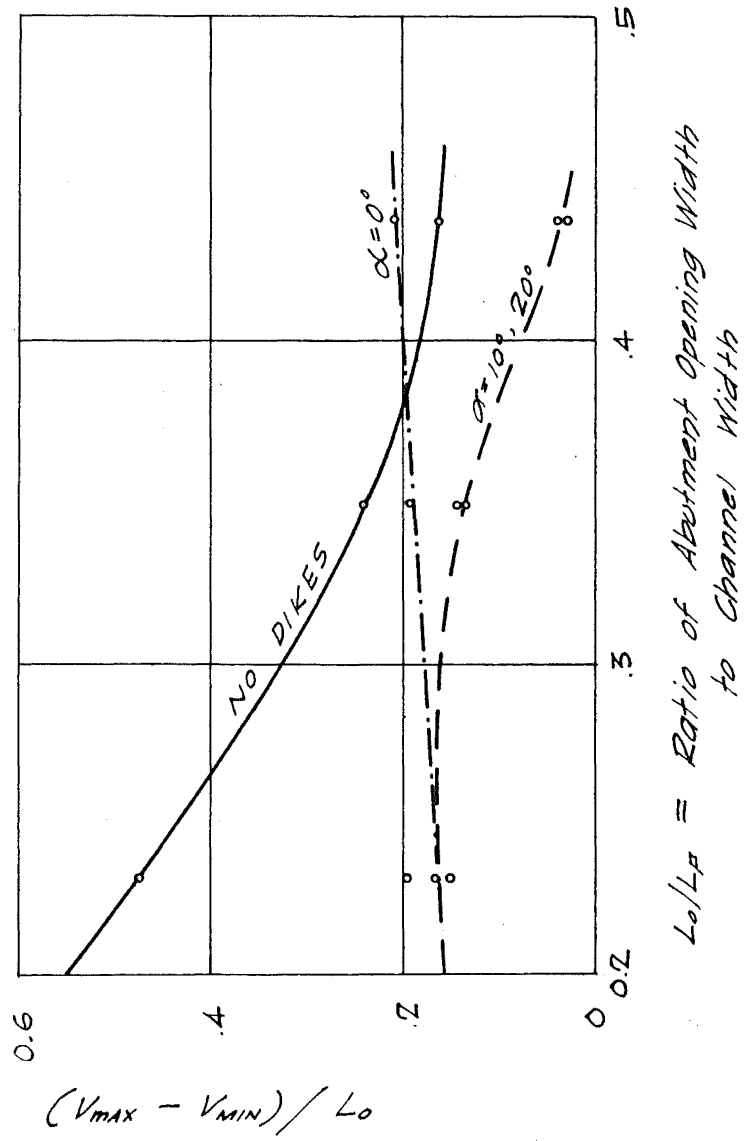


FIG 12 - Uniformity of Velocity Distribution

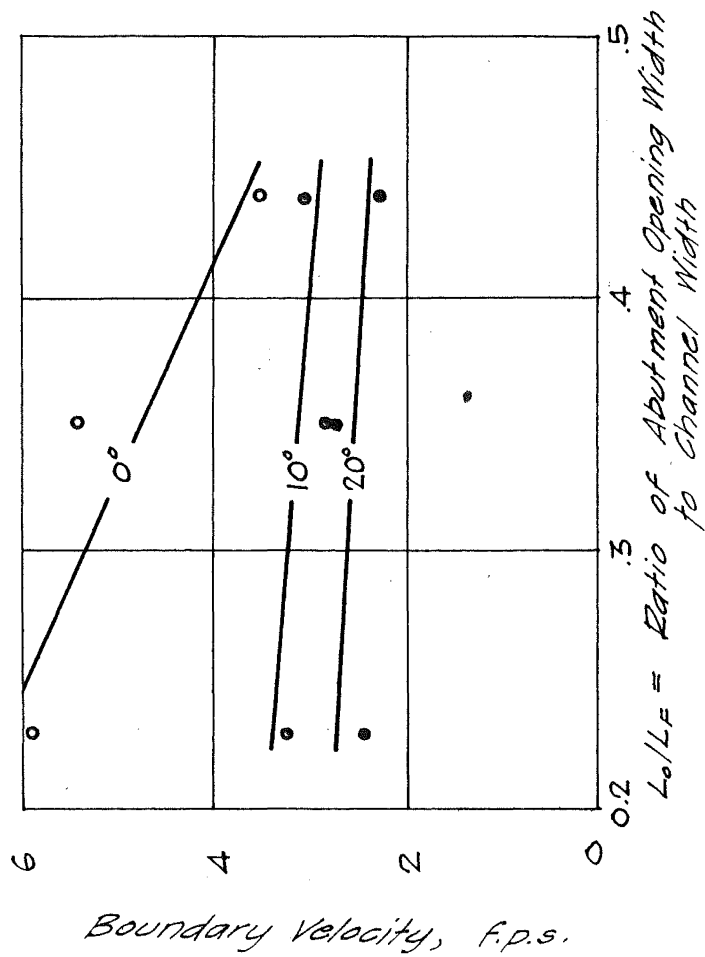


FIG. 13 - Velocity at Head of Dike

at the abutment corner should be eliminated by making the dike tangent to the abutment; second, the dike should be curved gradually from the tangent upstream to its head. Besides providing a gradually increasing rate of transition to the flow, a curved shape helps suppress the growth of eddies.

Indeed, when such dikes made in the shape of a spiral, were tested, it was found that a very uniform velocity distribution resulted (Figure 14) and eddies were virtually eliminated. From the test results it was decided to use this shape in the moveable bed model.

8.5 Conclusions

From the tests it was concluded that:

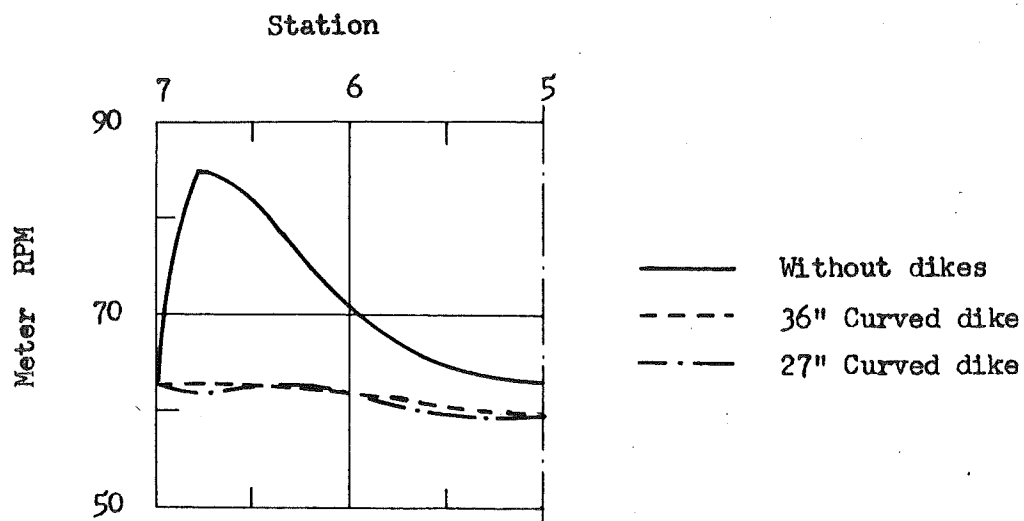
(1) Of the straight dike configuration those joining abutment at angle $\alpha = 20$ with the flow direction most nearly fulfilled the performance criteria, although they were only slightly as effective as the spiral curved dike

2) The spiral curved dike joined to the abutment by a tangent was effective in fulfilling the performance criteria.

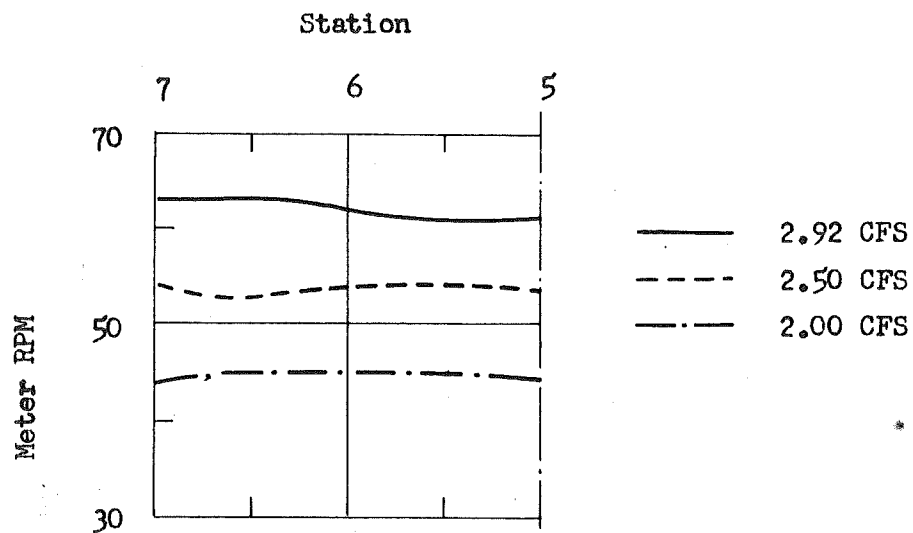
9. MOVEABLE BED STUDIES

9.1 General

For the moveable bed model tests a fairly uniform medium



(a) Velocity distribution for different length curved dikes



(b) Velocity distribution for different discharges

Fig. 14 - Velocity distributions for curved dikes.

sand (Fig. 15) was purchased from a local supply house and the flume modified for the tests. A discharge (0.955 cfs.) was chosen which would just not scour the bed of the flume without the model in place (Photo No. 4). The tail gate was adjusted to give a depth of 0.25 feet at the center of the abutment. After running the model until equilibrium was reached (about two hours) wool yarn was used to describe the contours of scour and deposition (Photo No. 5-7).

In one spur dike configuration two discharges were used (1.32 cfs. and 0.955 cfs.) and an analysis of scour depths was made. In the case of 10^0 angled dikes, it was found that the mean depth varies as the $2/3$ power of the discharge (Fig. No. 16). The proportionality is the same found by Leopold and Wolman¹⁰⁾ for scour between bridge piers on the Powder River, Arvada, Wyoming. The local scour at the head of dikes was found to be proportional to the discharge (Fig. No. 16).

9.2 Observations

The contour plots which are shown in figures 17 and 18 readily describe the erosion patterns.

It will be noticed that without dikes deep scour occurred along the abutments, particularly at the upstream corners of both

BEFORE



Photo No. 4

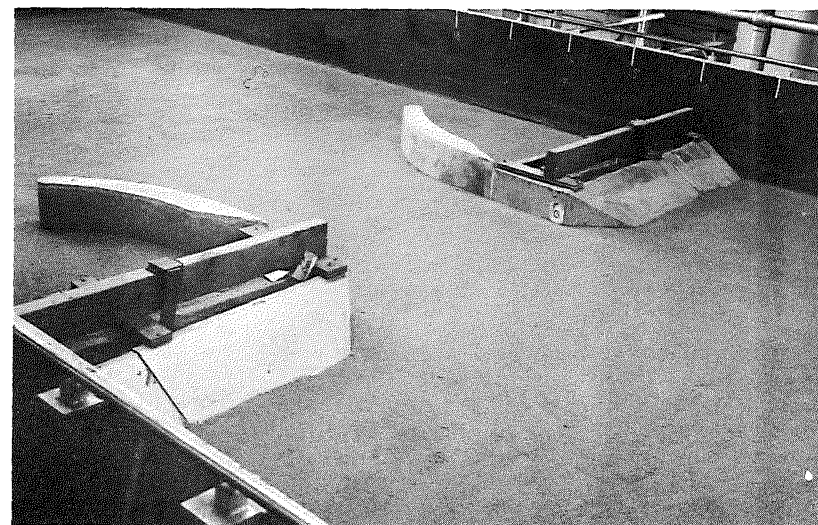


Photo No. 5

AFTER

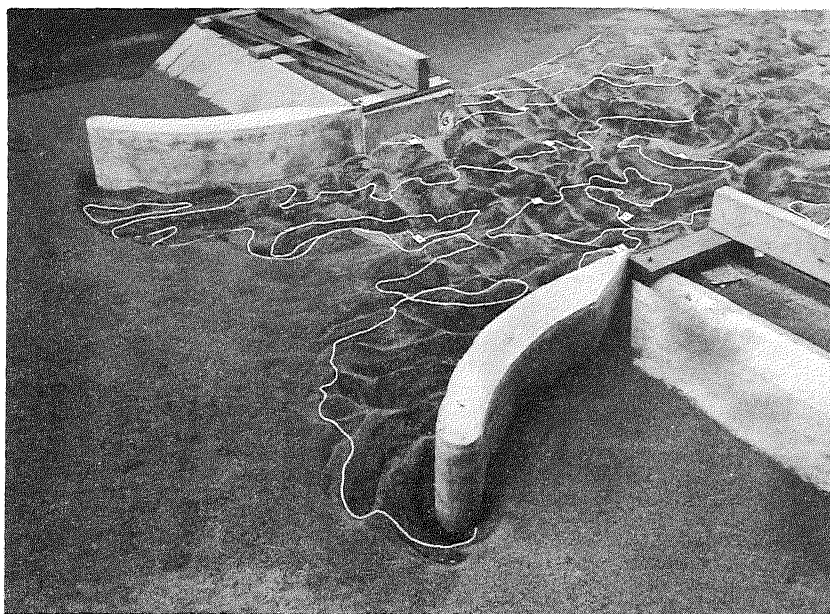


Photo No. 6

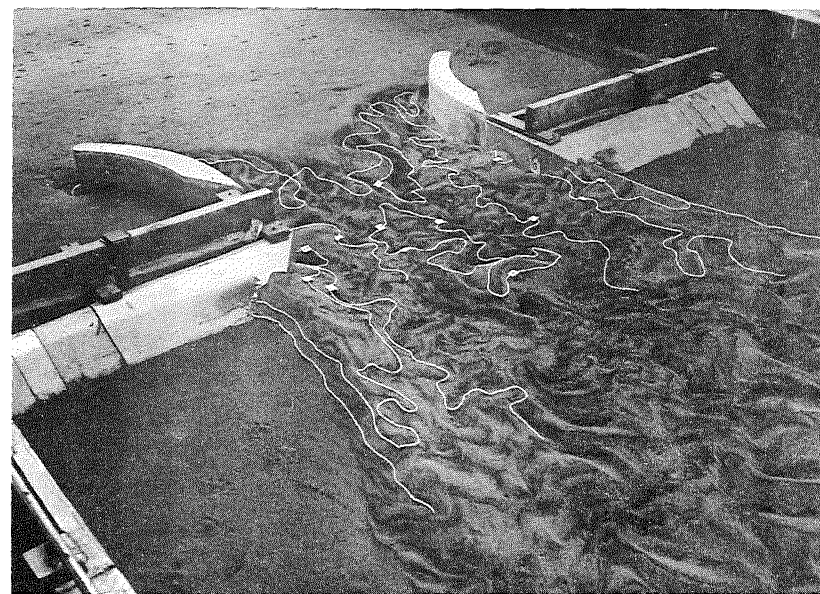


Photo No. 7

Upstream View

Oblique View

SCOUR TEST OF DEC. 16, 1960 - With Curved Dikes

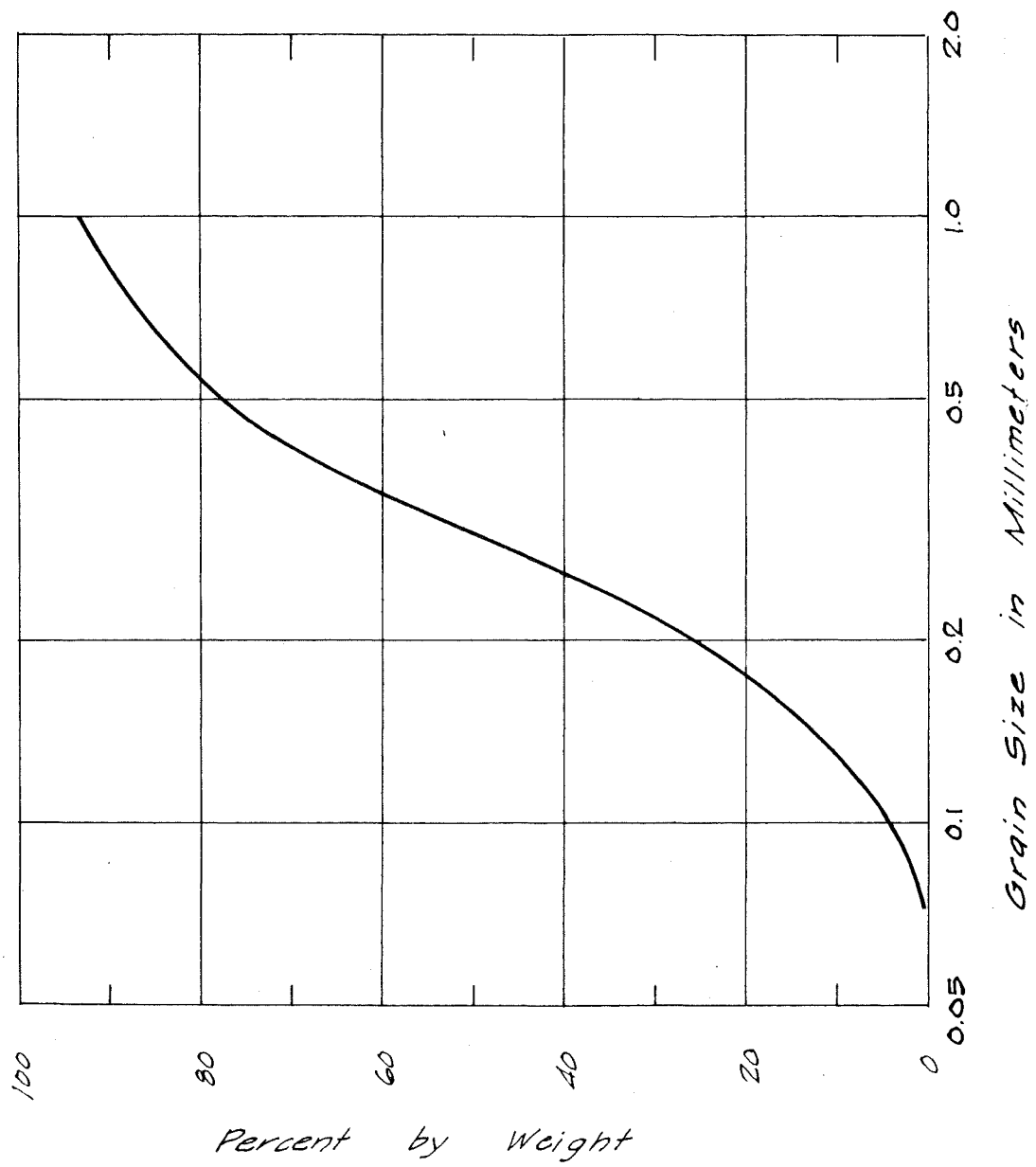


Fig 15 - Grain Size Distribution

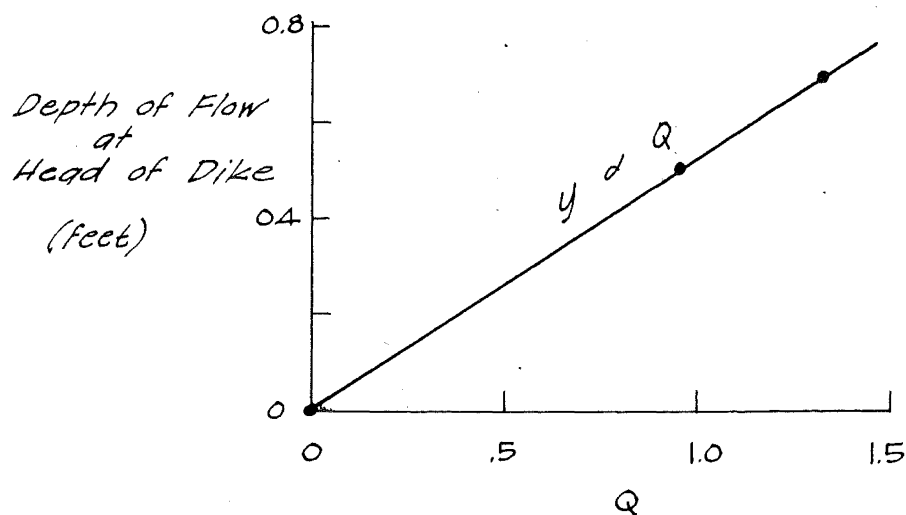
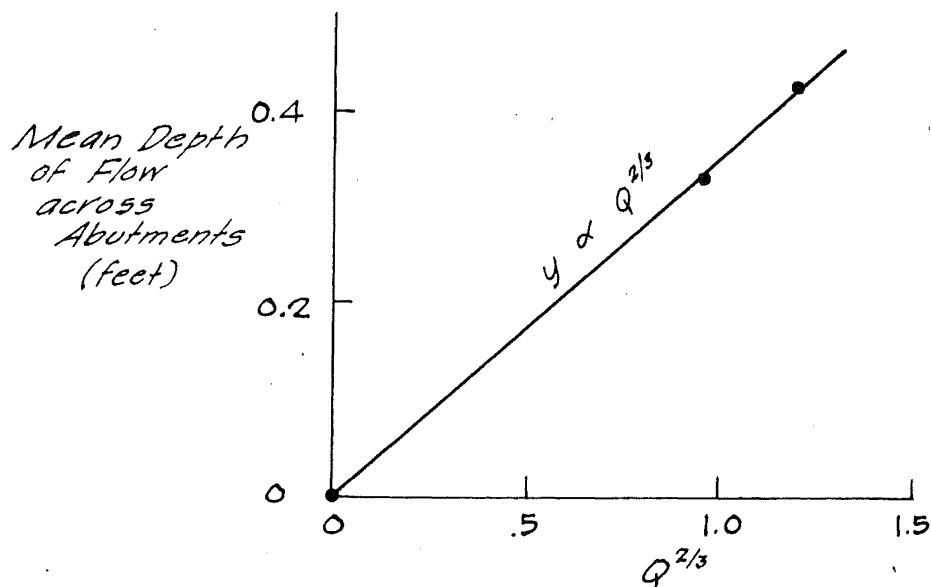
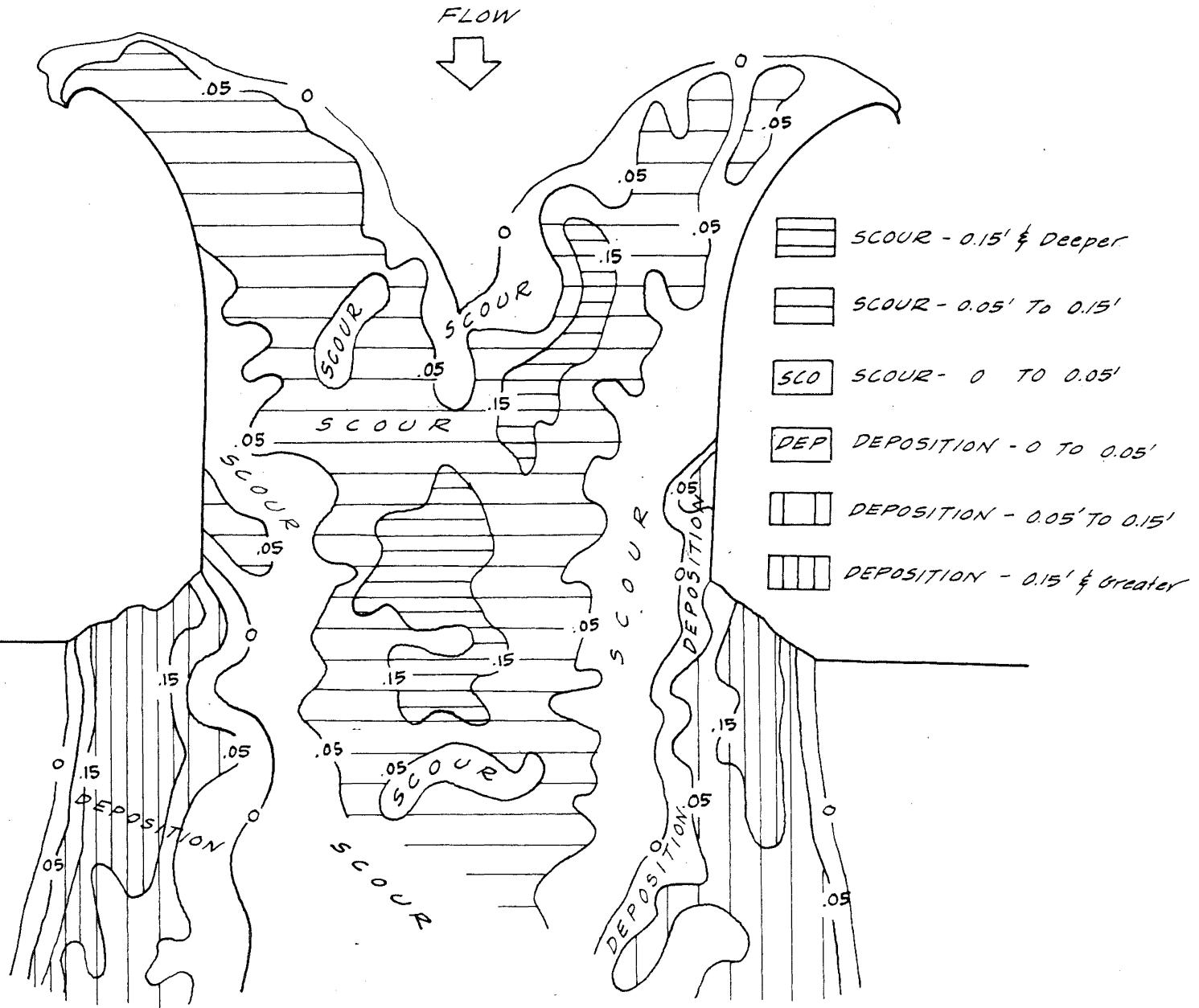


FIG. 16 - Scour - Discharge Relations for Moveable-Bed Tests

FIG 18 - CONTOUR PLOT OF MOVEABLE-BED TEST WITH CURVED SPUR DIKES. $Q = 0.955 \text{ cfs}$



abutments; in the fixed bed model local high velocities and depression of water surface occurred at same corners. In contrast, the curved dike considerably decreased the scour along the abutments. In both cases, deposition occurred at the downstream corners, thus removing the need for stub dikes.

A test run with straight dikes angled at 10° showed a lessening of scour about the abutments, but severe scour occurred at the upstream end of the dikes, while straight spur dikes may reduce the velocities at different abutment sections, they do not offer a continuous transition into the abutment, and in sharply intercepting the flow they create locally deeper scour than original abutment situation. Although in some cases it may be advantageous to protect abutments by failure of a dike, it is almost always a waste of time and effort to construct dikes which are poorly designed and offer little security.

9.3 Conclusions

Further consideration of the test of the spiral shaped dikes leads to several conclusions:

1. The curved dike, in providing a smooth transition for the flow was extremely effective in reducing scour effects at the abutments. At some points, deposition occurred along the abutments

where, without dikes, scour would have developed.

2. Less scour occurred along the dike than occurred at the abutment corners when the model was tested without dikes.

3. Construction of a properly designed dike will significantly increase the safety of bridge abutments against scour while producing a safe dike.

9.4 Design Recommendation

1. A correct shape of curved dike eliminates eddying at the head of dike, at the junction of dike and abutment, and makes the velocities uniform.

2. Testing shows that a spiral is a suitable shape to fulfill the requirements.

3. The length of dike by itself is not important. Length is required to develop a certain shape. That shape is a curve, tangent at the abutment, slowly turning away from the main stream lines to a point having a distance of one-tenth or one-eighth of the full width of channel from the edge of abutment.

4. The dike shape should be determined for maximum flow to be expected. This will give a satisfactory flow for lower discharges.

5. Shape and length of dike depends upon discharge. In case of high discharge, the shape of the dike should change very gradually. This will make the dike longer than for low discharge where the transition need not be so gradual.

6. It should be borne in mind that highest velocities in the transition would be along the dikes. Measures should be taken against it while designing and building a dike.

10. SUMMARY

Tests of spirally shaped spur dikes attached to a bridge abutment model showed the potential of spur dikes to protect the abutment from damage due to scour. Not only did the dikes significantly reduce maximum scour depths, but they moved the points of deep scour away from the abutments.

The assumptions made in the fixed bed model testing that uniformity of flow and reduction of eddies produced less scour were verified by the moveable bed model testing.

For abutments placed normal to the flow and at 60° to the flow, the best shape of dike arrived at was a spiral. In both cases it should be tangential to the abutment. It was found in 60° skewed abutments that, for best results, dikes should be used on both sides of abutments.

11. RESEARCH RECOMMENDATIONS

In further research on moveable bed models, answers should be sought to the following questions:

1. What relation exists between prototype scour depths and model scour depths?
2. For different abutment openings, what curvature and minimum length of spiral dike will produce the optimum conditions?

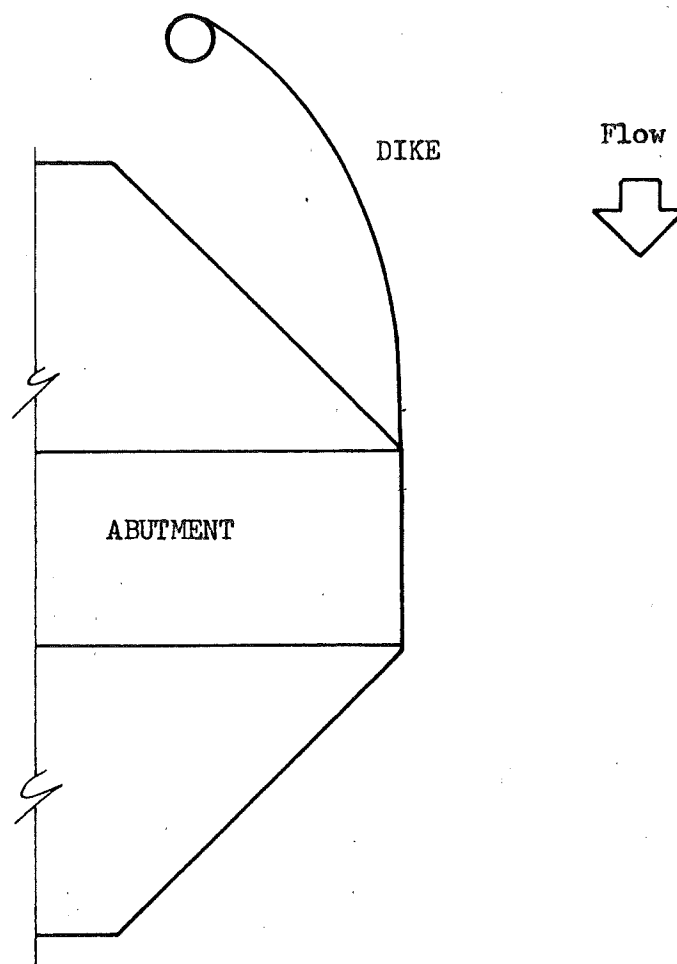


Fig.19 - Best shape for curved spur dike.

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